The Kidsat Project Flight System

Submitted to the IEEE Transactions on Geoscience and Remote Sensing

Author:
John D. Baker
Jet Propulsion Laboratory
4800 Oak Grove Drive, MS 301-490
Pasadena, California 91109
(818) 354-9464

Co-authors:
Jonathan Woodring
Ohio State University
Columbus, Ohio 43210
(419) 822-3529

Austin Leach, Joshua Lane
La Canada High School
La Canada, California 91011

Robert Spohr
Electronic Still Camera Project Engineer
Lockheed-Martin, NASA Johnson Space Center
Building 15
Houston, Texas 77058
(281) 438-1112

Abstract - This paper was written to discuss the technical aspects of granting students in classrooms the ability to explore and study Earth Sciences from a unique view of our planet. A high-resolution digital imaging system mounted in the Space Shuttle cabin window made it possible in part, to provide real-time student interaction with the space program. This access provided an individual ownership of research and interest in our environment and Earth sciences. The other project technical elements, also key to the program success and real-time student interaction, were the UCSD web-based Mission Operations system and the JPL Ground Data System.

TABLE OF CONTENTS

1. INTRODUCTION

The Kidsat project was started with the afore mentioned objectives in mind and became a three year flight-education pilot program. It was unique in that it combined the real-time aspects of manned space flight with middle school education.

The Kidsat project was led by the Jet Propulsion Laboratory which was responsible for the overall flight system development, the data system development and the science content. The Johnson Space Center Electronic Still Camera (ESC) Project was responsible for providing the digital camera equipment and for supporting the integration and testing before flight. The Johns Hopkins University Institute for the Academic Advancement of Youth developed the classroom curriculum, and the University of California San Diego developed and led the mission operations.

The flight system was developed to operate on board the Space Shuttle and provide students the opportunity to photograph the Earth from their classrooms as an astronaut would from orbit. Using a digital camera for remote sensing and specially designed software, this extraordinary view gave them the ability to study, appreciate and to newly perceive the Earth on which they live and their environment in a new way. Overall, there were three successful flights of the system (STS-76, STS-81, and STS-86) taking 1522 pictures during 146 hours of operation. Each of the flights was a Mir Space Station resupply mission.

The educational component of the program was divided into two parts. The first was to develop a curriculum around the target sites, experiment operation and data image products. This provided an opportunity for the education and flight project communities to come together and create new curriculum, terminology, and an appreciation for the others' professional discipline. The target audience was middle school students in pilot classrooms throughout the United States. The students used the internet to plan picture taking opportunities and view the areas of the Earth that they were studying to hypothesize and discover for themselves something about our planet. Such an example is shown in Figure 1. The image contains rural ghettos which are remnants of the apartheid era in South Africa. They line the edge of Kruger National Parks, one of the largest in Africa. Inside the park, the dark regions indicate that the game wardens may have been doing some burning to get rid of the over growth.

Figure 1. Rural ghettos along the South African- Zimbabwe border from STS-86.

The second educational component was achieved by including students in mentoring relationships with principal members of the project. JPL personnel involved with the flight system element worked with twelve high school and undergraduate students during the three-year program and allowed them to contribute and participate in many different ways. The undergraduate students were responsible for developing and testing the flight software and the high school students assisted with the operation of the flight system. Before each flight, students went to the Johnson Space Center to verify procedures and perform astronaut training.

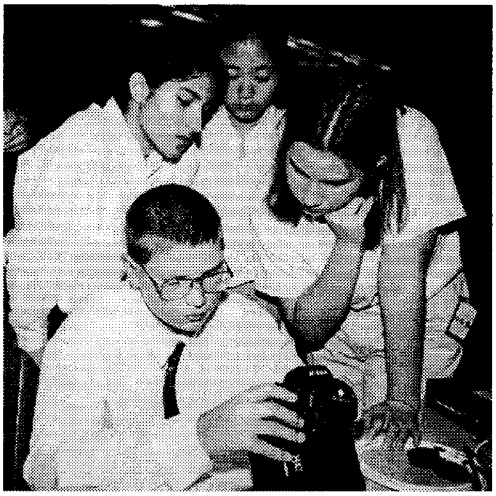

Figure 2. Students at JSC working with equipment

Figure 2 shows several students from the flight team Doug Shepherd, Noosha Amiri-Davani, Vanessa Vanasin and Kelly Winters working at JSC verifying the flight procedures. Senior engineers advised and performed the final flight qualification tests.

2. SYSTEM OVERVIEW

The Kidsat flight system was developed using Space Shuttle program provided hardware components to minimize cost. The two unique additions were the mission specific software that allowed remote operation of the digital camera system from the ground and a SCSI (Small Computer Standard Interface) connection between the camera and the notebook computer.

There were a number of design drivers that made the development and execution challenging. Since the Kidsat experiment was classified as a secondary payload, we were required to minimize crew interaction, payload integration time and utilization of orbiter resources. We also had to deal with the remote operation aspects without having real-time telemetry. Lastly, we had limited operational windows during each mission so we wanted to get the most out of each opportunity for the students. Operations were organized around the primary mission objective of docking and resupplying the Russian Mir Space Station as well as the orbiter attitude timeline.

Several key technologies became available at the beginning of the program in 1994. They were the high resolution Kodak Digital Still Camera and the JSC developed Orbiter Communications Adapter (OCA). These made our experiment possible and economical.

To meet the secondary payload requirements, we designed the experiment to operate relatively autonomously by receiving files of ground commands. It ran in 'batch' mode by processing each file on arrival. These files consisted mostly of time-tagged 'Photo' commands which were used to take pictures at a specific Mission Elapsed Time (MET). The orbiter's location over the Earth, referenced by MET, was determined by the operations team to allow the students in the classrooms to plan their picture taking. After MET time-tagged photo commands had been executed, the image and log files were downloaded to the ground via the OCA during the night side of the orbit. The files were first archived at JSC and then sent to JPL for image processing and UCSD for analysis and targeting.

Given the batch mode of operation, there were data latency issues for the payload operations. Since it was often hours before we knew how the flight system had performed during the last picture taking pass, diagnosing a problem based on the log and image files and closing the loop with the JSC Mission Control Center (MCC) team and ultimately the flight crew took considerable time. During the first two flights, a number of different problems were encountered, both technical and operational in nature. These lessons learned were incorporated into the final redesigned version of the flight software. Built-in fault detection and assessment with a beeping alert was added. Once an alert sounded, a simple chime, the crew would evaluate and remedy the situation and notify the operations at the MCC of the situation.

The high-resolution digital camera generated raw image files, 6.4 MB in their unexpanded form. The flight system experienced storage and data throughput limitations during several orbits where nearly 500MB of images were taken. This proved taxing to the entire system. To address this issue, the final version of the software also included loss-less image file compression capabilities in which the software would rapidly compress the image files before transmission to the ground through the Ku-band link. Loss-less compression was used to retain image resolution. This reduced our on-board storage and the down-link time requirements by more than 60%. The next limitation was simply the availability of targets or ground sites.

3. SYSTEM TECHNICAL DESCRIPTION

On the Space Shuttle, the Kidsat flight hardware and software were the heart of the flight instrument operations. Ground command files were processed and photographic requests were then queued and executed. Within hours, students in classrooms and on the payload operations team were able to see color images of the sites they had requested. The payload was composed of five main components.

1. The Electronic Still Camera (a NASA modified Kodak DCS-460C),
2. The camera photo bracket,
3. A ThinkPad 755C in a docking station, referred to as a PGSC (Payload General Support Computer),
4. The OCA Ku-band data link installed in the PGSC docking station, and lastly
5. The Kidsat Flight Software residing on the PGSC.

The diagram in figure 3 also includes the Ku-band system link to the Tracking and Data Relay Satellite System. The cargo-bay video cameras were used once on STS-81 but getting the video to the classrooms proved too difficult. Also, the ESC resolution was considerably better than the video system for studying the target sites.

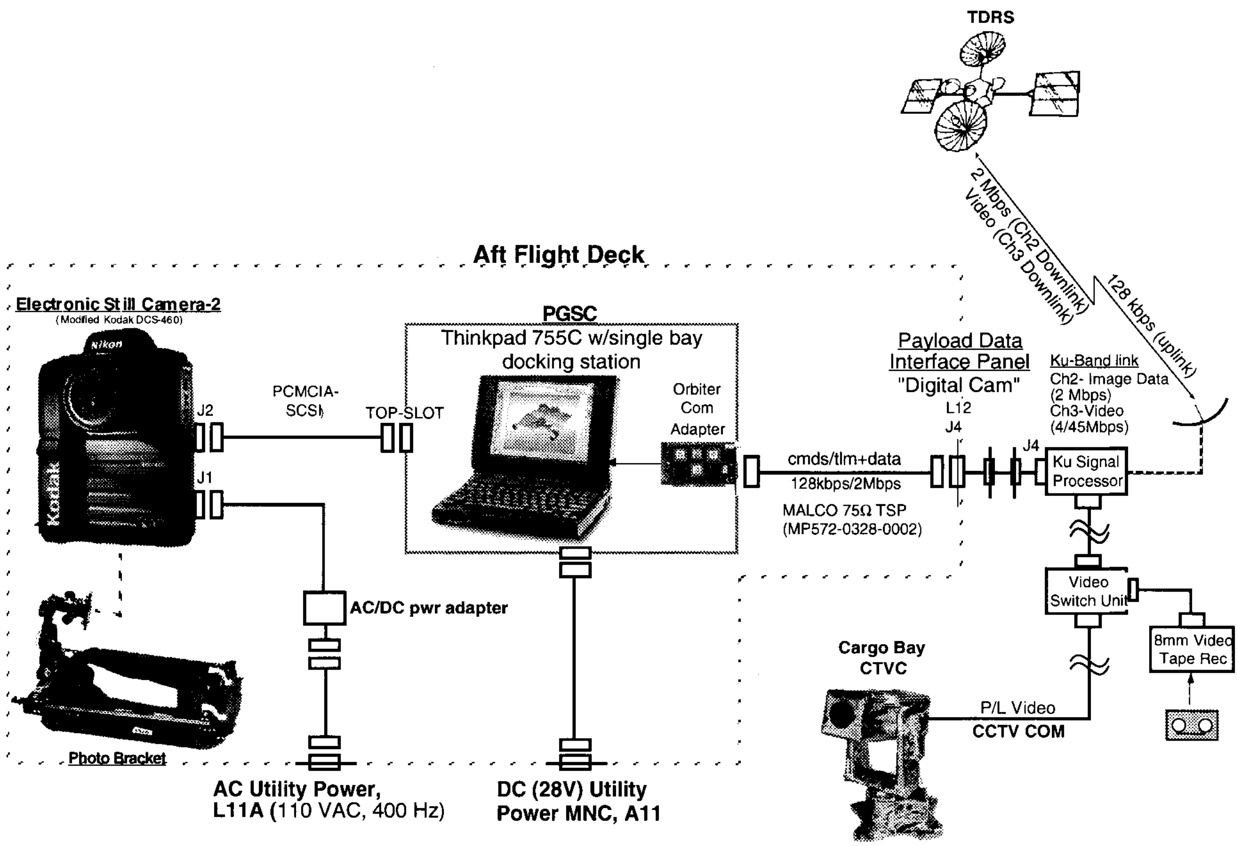

Figure 3. Flight System Wiring Diagram

The Electronic Still Camera is based on a commercially available Kodak DCS-460C Color Professional Digital Camera System (DCS). It uses a Nikon N90S camera backed by a color CCD image acquisition system. This camera system also includes PCMCIA disk services for storage and SCSI services for data transfer to outside systems such as the PGSC. The Johnson Space Center modified the camera for flight use. The modifications included battery fusing and firmware changes to allow the camera to operate with a larger ISO range.

The acquired images were in a Kodak proprietary TIFF format using the 2036 x 3060 pixel sensor. Each image file was 6.4 megabytes in size for the over 6 million pixels. During post processing the image files were expanded to 18MB, by spectrally averaging each pixel with its neighboring four pixels. The spectral sensitivity range of the sensor, as supplied by Kodak, was approximately 400nm to 700nm.

The camera was able to operate at an average frame rate of one image every 8 seconds or in burst mode by acquiring two images in 2 seconds. This was accomplished since the camera could store two images in dynamic RAM before writing to disk. The operation team used this feature to take overlapping image scenes and create mosaics of popular targets for the classrooms. Overlapping images were also turned into stereo-pairs, giving the viewer an appreciation for the terrain and cloud structure. The frame rate was limited by the PCMCIA hard disk card access time. The camera could take and store 40 images per orbit on its 260 Mbyte hard disk card.

Three lenses were flown for each flight. A 50mm, 85 mm and a 180mm lens were flown. The 50mm lens was installed during the first operational period of the mission. During the latter two flights, the 85mm lens was a popular selection. Both provided excellent resolution and a large enough swath to be able to understand the context of the terrain. The diagram in Figure 4 contains a table with the approximate swath widths for the two more popular lenses. The swath widths listed assume an altitude of 400 km and take into account that the camera CCD aperture was smaller than the standard 35 mm film so the actual field of view is smaller, effectively giving us a higher focal length.

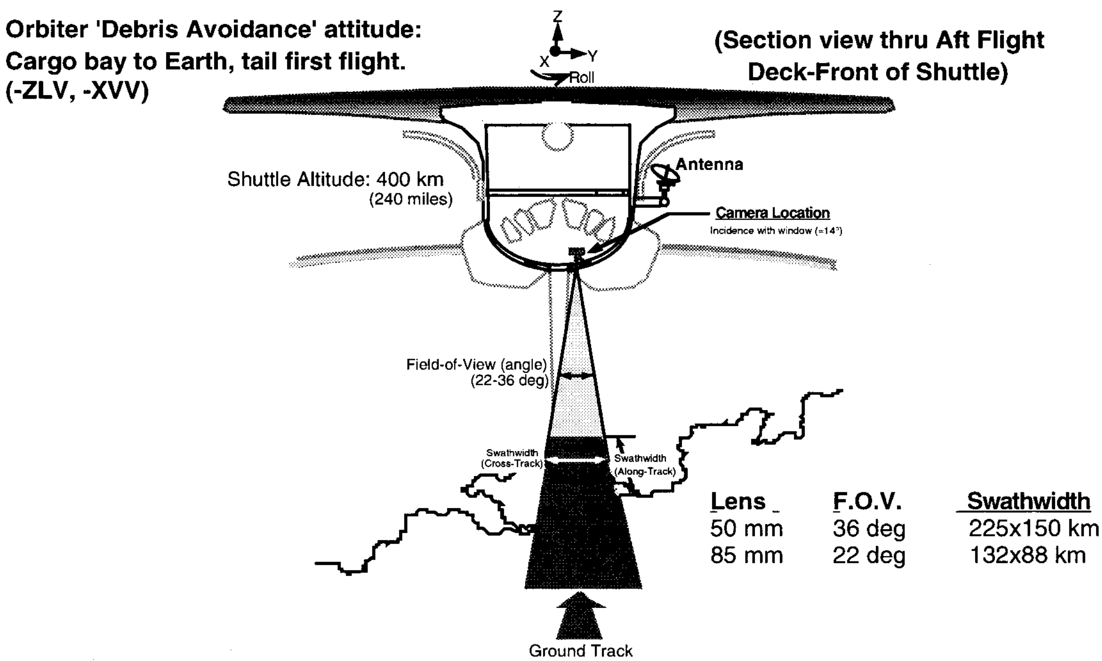

Figure 4. Kidsat Photo-taking Geometry

Mounted in the starboard overhead window on the flight deck of the Shuttle cabin, pictures were taken only while the Shuttle was in the -ZLV attitude (cargo-bay to Earth) flying tail first to avoid debris damage. The picture below shows the camera as mounted onto its bracket. The bracket mounted into the window frame using the window shade clamping system. The bracket was adjustable and allowed the camera to be tilted +20° to -40° cross track if the orbiter was rolled or in a –ZLV bias state. In figure 5, we can see the Earth's horizon and the tail of the orbiter through the rear. Two STS-81 crewmembers, Mission Specialist John Grunsfeld and Commander Mike Baker are observing. Mission Specialist Marsha Ivins took the picture.

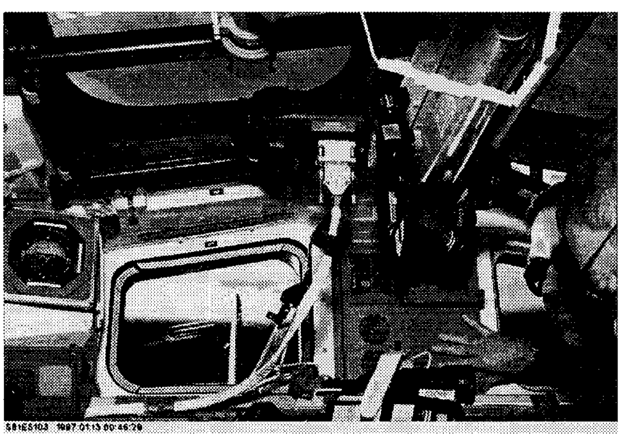

Figure 5. ESC Mounted in Orbiter Window, NASA PAO Photo S81E5103, STS-81

The software operated on an IBM Thinkpad 755C notebook computer with a 486DX75 CPU running Microsoft Windows 3.1 during the first flight (STS-76, Feb '95) and Windows '95 for flights STS-81 and STS-86. The PGSC had 32 MB of RAM memory and an 810 MByte hard disk. The Kidsat experiment shared the PGSC with the Orbiter Communications Adapter (OCA) mostly for convenience due to the data volume. The OCA enables high-speed synchronous data transfer from the Mission Control Center (MCC) to and from the Space Shuttle Orbiter. The Electronic Design and Development Branch/EV2 developed this capability at the Johnson Space Center. Shuttle to ground data transmission was accomplished through the orbiter's Ku-band antenna system which relayed the data through the Tracking and Data Relay Satellite System (TDRSS). The down link rates were 4Mbps using Ku-band channel 3 or 2Mbps using Ku-band channel 2.

OCA performance in the shared configuration was impacted slightly during the first two flights but software multi-tasking improvements to the Kidsat flight software made joint operation with the OCA unnoticeable during the last flight. While designed to operate over a LAN (Local Area Network), the Kidsat PGSC was never configured in this manner during the flights.

4. FLIGHT SOFTWARE

The Kidsat flight software, which resided on the ThinkPad, ran all experiment operations onboard the Shuttle. During the experiment setup, the crew first unstowed the equipment from the lockers, configured the system and started the software. The crew checked out the system by taking a photo using the command window. Once setup and checkout was complete, crew intervention was not required and ground operators at UCSD began sending command files or CCFs (Camera Control Files) to the system.

The software evolved substantially over the pilot program for many different reasons. The primary drivers for the modifications were to make flight and ground operations simpler and more robust. This was accomplished by designing the system for 'operability' and adding built-in fault detection and assessment with alarming. The alarming and fault assessment allowed the crew to respond quickly to problems versus waiting for the ground to request action. System throughput and storage limitations were also issues and were addressed by adding image data compression.

Eric Vandeveld, Joseph 'Skip' Reymann and John Baker wrote the first version of the software. It was a Win16 application, which also ran on a ThinkPad running Windows 3.1. The second version of the software, written by Jeff Lawson, Jon Woodring, and John Baker, was a revised and upgraded version of the original code which addressed a couple of software bugs and provided more functionality. It also was a Win16 application, but on the second Kidsat flight, the PGSC was running Windows '95 as its operating system.

The third and final Kidsat version of the flight software, written by Jeff Lawson, Jon Woodring, and John Baker, was a completely redesigned and rewritten version. Loosely based on the original code base, it provided the same functionality and added many more features. It consisted of a bundle of Win32 applications, DLLs, and OLE-services. The last version was designed in conjunction with the Mission Operations team from UCSD. The joint design effort proved valuable to both teams since the operations team had a better appreciation for how the flight system worked and the flight team understood how it was going to be operated.

The main code base was written in C++, with many object-oriented features implemented, such as abstraction of the camera, timekeeping units, and other such functions. It was compiled in Borland C++ 5.01 and also used the Borland ObjectWindows class API for the GUI interface and class abstraction. Microsoft Visual C++ 4.0 was used in building the Flight Software Helper application for interfacing with the camera. The camera control interface was implemented using a modified Kodak Professional Digital Camera API. The freely available ZLIB compression library was used to implement image file compression compatible with GNU GZIP/GUNZIP.

The flight crew software command interface was done using a graphical user interface (GUI) as shown in figure 6. Besides affording the crew a lot of control over the system, it also supported integration and testing. Written in ObjectWindows, the main executable GUI was a basic Windows dialog box, with several buttons along the left-hand face, several information windows, a status window, progress indicator, and a thumbnail image viewer. The buttons allowed the crew to test the system by taking a photo immediately, schedule a photo, view the log file or command queue, inhibit or terminate Kidsat operations. The window also displayed the current mission elapsed time, time remaining to the next photo take and available disk space. The thumbnail provided a color image of the last downloaded image from the digital camera to the PGSC, while the progress indicator was an animation to indicate to the crew that a download from the camera was in progress.

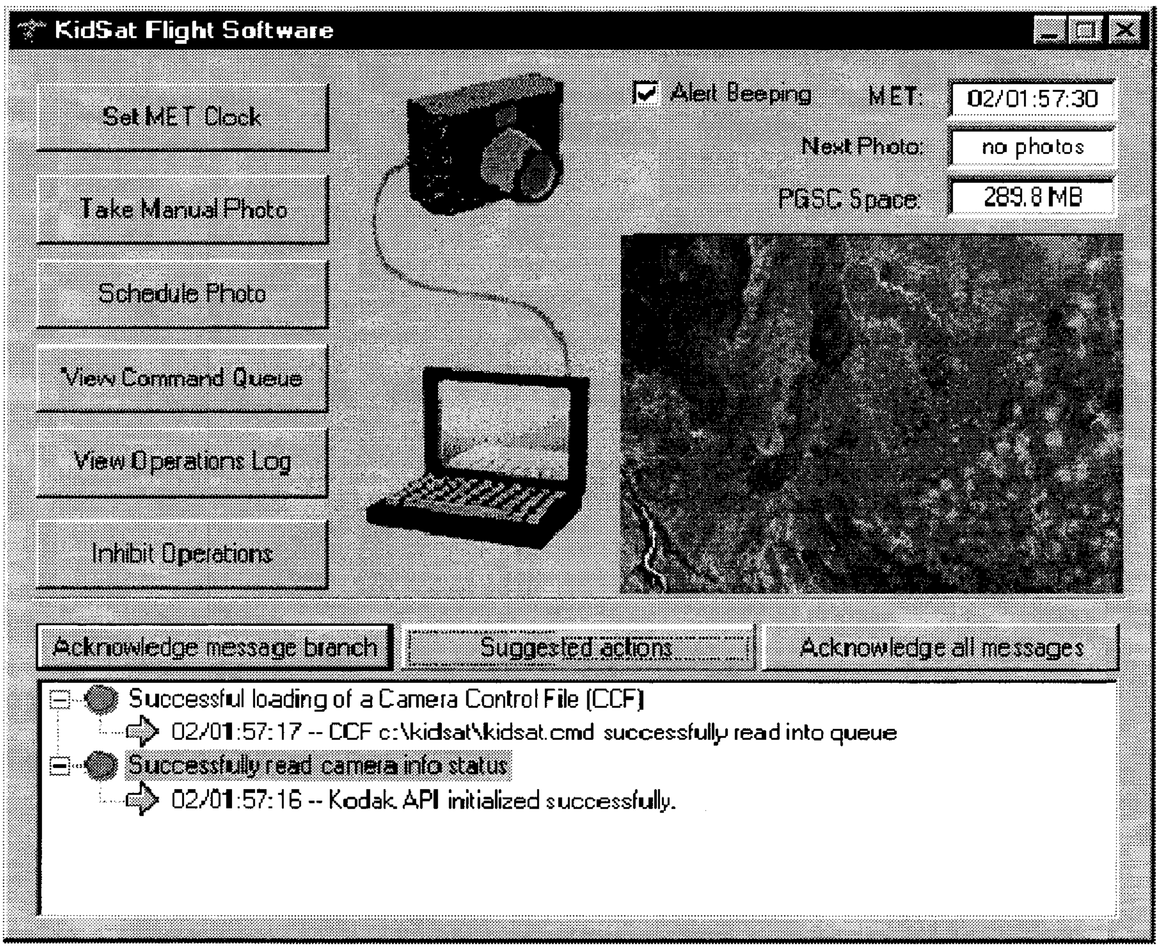

Figure 6. Kidsat Flight Software GUI/Front Panel

The status window displayed green dots as shown above or alerted them to error conditions. This was indicated by the green dots turning to a red stop sign. The status display also cleared itself if an error was corrected. The crew was able to obtain more information as well as look at suggested actions for the error. The alert was disabled during crew sleep periods.

The software was divided into two primary modules. The main module performed nearly all of the functions while a second module was created to interface with the camera.

The main software module performed timekeeping and command queuing based on time ordered commands from the ground. The system was required to take a picture within one second of the scheduled command execute time. We were able to achieve an accuracy of +/- 100ms. Performing relatively accurate timing events while using the Windows '95 operating system, the Kodak API and camera in this manner proved to be challenging. During the first two flights the Electronic Still Camera Group at JSC supplied a simple camera driver. The driver had limited functionality so for the third flight, we used the Kodak supplied Application Programming Interface (API). The final 'as flown' API, was customized by Kodak for the DCS-460C flight camera to improve shutter command response timing. The modification involved eliminating other unused camera product protocols and software imposed shutter command-timing limits.

The second module was named the Kidsat Helper and its primary function was to interface with the camera. It linked with a Kodak provided Dynamic Link Library (DLL) that provided software control interface to the DCS460C camera. This software was compiled into a separate executable, using a Microsoft Visual C++ compiler, since it was more compatible with the Win32 calling conventions of the Kodak API. The camera software interface linked with the API provided camera shutter control and image data transfer capability from the PCMCIA hard card to the ThinkPad hard disk for storage. The camera status provided data such as camera body settings, power adapter information and PCMCIA hard disk information.

The capability to receive orbiter telemetry using the PCMMU (Pulse Code Modulation Master Unit) interface from another PGSC on board was developed but never used. It was designed to give ground operators visibility into PGSC clock drift, which could be significant (several seconds per day) during a mission. Data were received from the PCMMU server using OLE services provided by JSC. The PCMMU server provided onboard Shuttle clock time and telemetry data.

Output from the Flight software came in two different forms, the LOG file, which contained key events and general status for the ThinkPad and the camera, and secondly the image data files. A directory structure was established to enable the OCA ground operators to know where to put and retrieve files. The log files, which were stored in two files, a comprehensive and a downloadable version, were an ASCII based file as well and contained a time ordered listing of all key events and component status. The file contained time of status condition, a status keyword, and a descriptive status field logged for every operation and error condition that took place in the software. Keywords were built into the log file structure for easy parsing and parameter searching on the ground enabling quick retrieval of the system status and error location. Only key events were logged to keep the file size down. The status and error conditions were verbose and easy to interpret by ground system operators.

5. SUMMARY

The Kidsat pilot program gave thousands of students a unique perspective of our planet, one that they could personally own and learn from. The payload flew successfully three times and was transferred to the University of California San Diego EarthKAM program and the Johnson Space Center in 1997 for continued development and operation. We accomplished a low cost remote sensing implementation on the Space Shuttle orbiter that allowed students in classrooms to view the Earth newly from a unique vantage point.

6. ACKNOWLEDGEMENTS

This project would not have been made possible without the thousands of inquisitive middle school students. This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California under contract to NASA. The project was sponsored by the NASA Education, Mission to Planet Earth, Space Science and Manned Space Flight organizations during the three-year pilot. We would like to thank Dr. JoBea Way for her vision of how space flight can contribute to education, Joseph 'Skip' Reymann who designed the original software architecture. The undergraduate students who participated were Jeff Lawson (Harvey Mudd), Jonathan Woodring (Ohio State University) and Eric Vandevelde (Stanford). The La Canada High School students Joshua Lane, Austin Leach, Doug Shepherd, Noosha Amiri-Davani, Vanessa Vanasin, Kelly Winters, Tim Farag and Steve Davis contributed considerably to the project in its development. Management support at JPL was provided by two project managers, Greg Goodson through the first flight and Mike Devirian during the remainder of the project.

We also want to thank Dr. Sally Ride and her student team for their partnership during the development and successful operation of the experiment. The Johnson Space Center Electronic Still Camera Project team played a key role and provided a lot of support and cooperation during many long days and nights of integration, testing and operations. Lastly, we want to thank the mission operations teams at the Johnson Space Center and the astronauts whose commitment to mission success contributed to an extraordinarily successful project.

BIOGRAPHY

John Baker is a senior engineer at the Jet Propulsion Laboratory (JPL). John was responsible for the Kidsat flight system development and flight operation during the pilot program. He is currently leading the redesign of the Mission and System design process at JPL. He has worked on several flight projects including the Spaceborne Imaging Radar System (SIR-C) which flew on the Space Shuttle twice in 1994 as a cognizant subsystem engineer and lead instrument operations engineer. John has also developed several new hardware and software technologies.

Jonathan Woodring started working with JPL during the SIR-C missions planning the crew photography activities and continued to participate in different roles during the Kidsat project. During the project, Jon attended the University of Southern California in Los Angeles and Ohio State University in Columbus and worked with the Data and Flight system development teams. Jon developed elements of the flight software and supported mission operations while on the flight team.

Austin Leach is a senior at La Canada High School. He plans to study bio-engineering in college and pursue a career in agricultural bio-engineering technology. Austin has participated as a student on the Kidsat flight team during the entire pilot project, he trained two separate astronaut crews and worked all three Kidsat missions operations at the University of California San Diego.

Joshua Lane is also a senior at La Canada High School. He plans to study medicine in college and pursue a career in space medicine. Josh participated as a student on the Kidsat flight team during the entire pilot project, he also worked with two separate astronaut crews and participated in all three missions operations at the University of California San Diego.

Robert Spohr is an Optical Engineer for Lockheed Martin at the Johnson Space Center (JSC). Rob was responsible for the Electronic Still Camera (ESC) during the STS-86 flight. He is currently responsible for redesigning the ESC for Space Station operations and supporting the EarthKAM project that developed out of the Kidsat project. Rob has developed new methods for the Shuttle crews to view and print ESC images on orbit.

REFERENCES

Way, J., Ride S., and Stork, E., Kidsat, 1995 International Geoscience and Remote Sensing, 1995.

Baker, J., NASA Headquarters Kidsat Project Review Presentation, JPL, Jan. 1996

Baker, J., Kidsat Space Element Flight 2 (STS-81) CDR presentation, JPL, Sept. 1996.

Woodring, J., Kidsat Space Element Crew Familiarization Briefing, STS-86, Jul. 1997